VORTEX DYNAMICS

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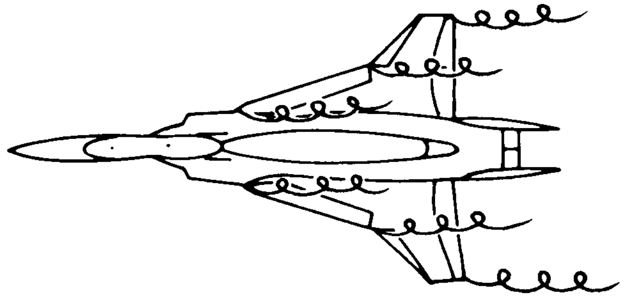
[redacted] VORTEX DYNAMICS

Vortex flows of interest to aerodynamicists cover a wide range of scales from a fraction of an inch in boundary layer flows to many feet in wake flows. In many applications these flows are poorly understood and, due to their complexity, present a challenge both analytically and experimentally. This paper describes four topics representing the spectrum of experimental and analytical vortex research.

- Long research history
- Many scales and applications
- Challenging research area



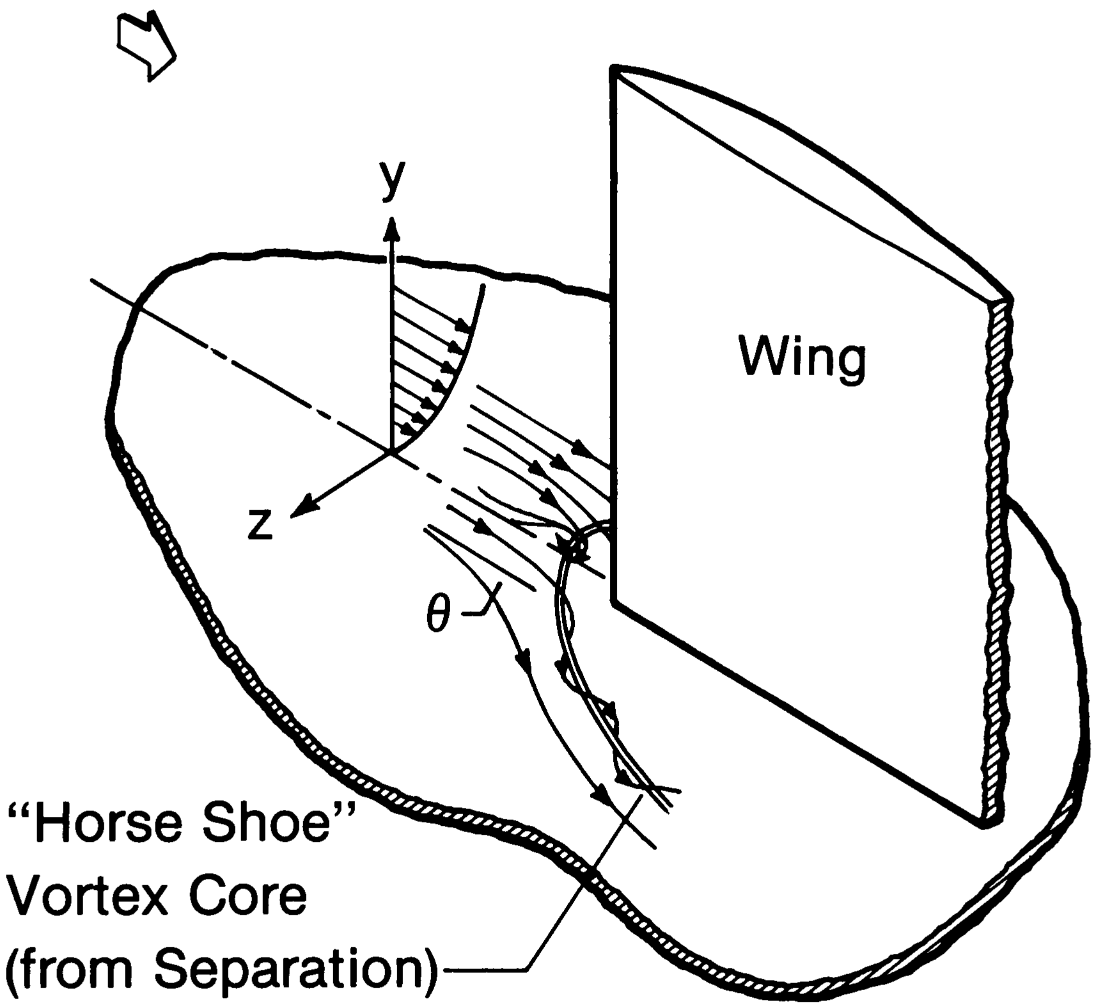
JUNCTURE VORTEX CONTROL

Juncture vortex control is important not only because of its direct contribution to drag but also because of its potentially unfavorable interaction with the wing boundary layer or other vortices.

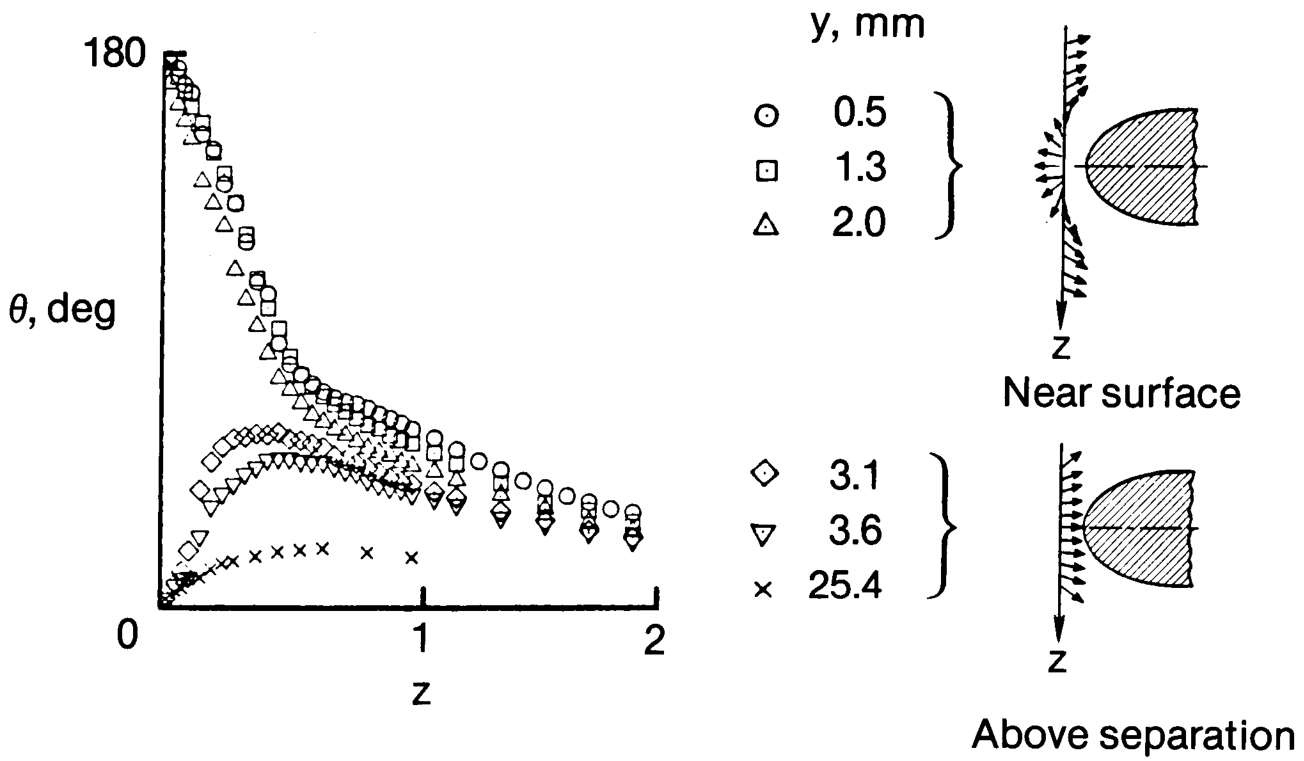
- Drag reduction
- Boundary layer control
- Vortex interactions

JUNCTURE FLOWFIELD SCHEMATIC

This figure shows a schematic of a juncture flowfield. A wing at zero incidence is mounted perpendicular to a flat surface. The x cordinate is aligned with the freestream velocity vector, y is perpendicular to the surface, and z is the lateral coordinate as shown. The flow direction angle, θ, is in the lateral or x-z plane. As the boundary layer encounters the adverse pressure gradient near the wing leading edge, it can separate with the separated region forming the core of the juncture vortex.



This figure illustrates one type of measurement used to understand the juncture flow. The lateral flow direction angle, θ, is shown as a function of the lateral coordinate, z, for a streamwise location just ahead of the wing. The symbols represent different heights above the surface. Near the surface there is a flow reversal ($\theta = 180^{o}$) near the wing centerline (near z = 0). Above the separated region, the flow angle behaves as expected allowing smooth flow around the wing. Although the measurements shown were made with a hot wire anemometer, a variety of techniques, including pressure probes and a laser velocimeter, are being used to study juncture flow control by fillets or other geometry modifications. Additional details of this research are described in reference 1.



IN-FLIGHT FLOW VISUALIZATION

The purpose of this resarch is to develop vapor-screen technology for in-flight visualization of the leading edge vortex over the wing of an F-106B aircraft and to understand the effects of Mach and Reynolds numbers on the overall flowfield.

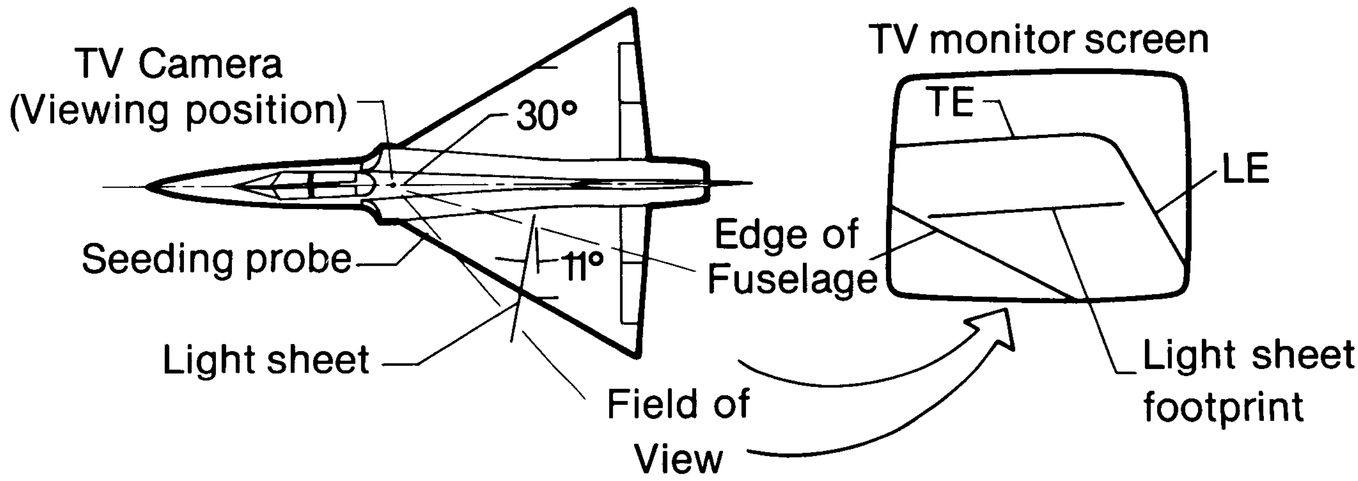
- Develop vapor screen technology for in-flight flow visualization
- Observe leading edge vortex system
- Understand Mach and Reynolds numbers effects

F-106B AIRCRAFT

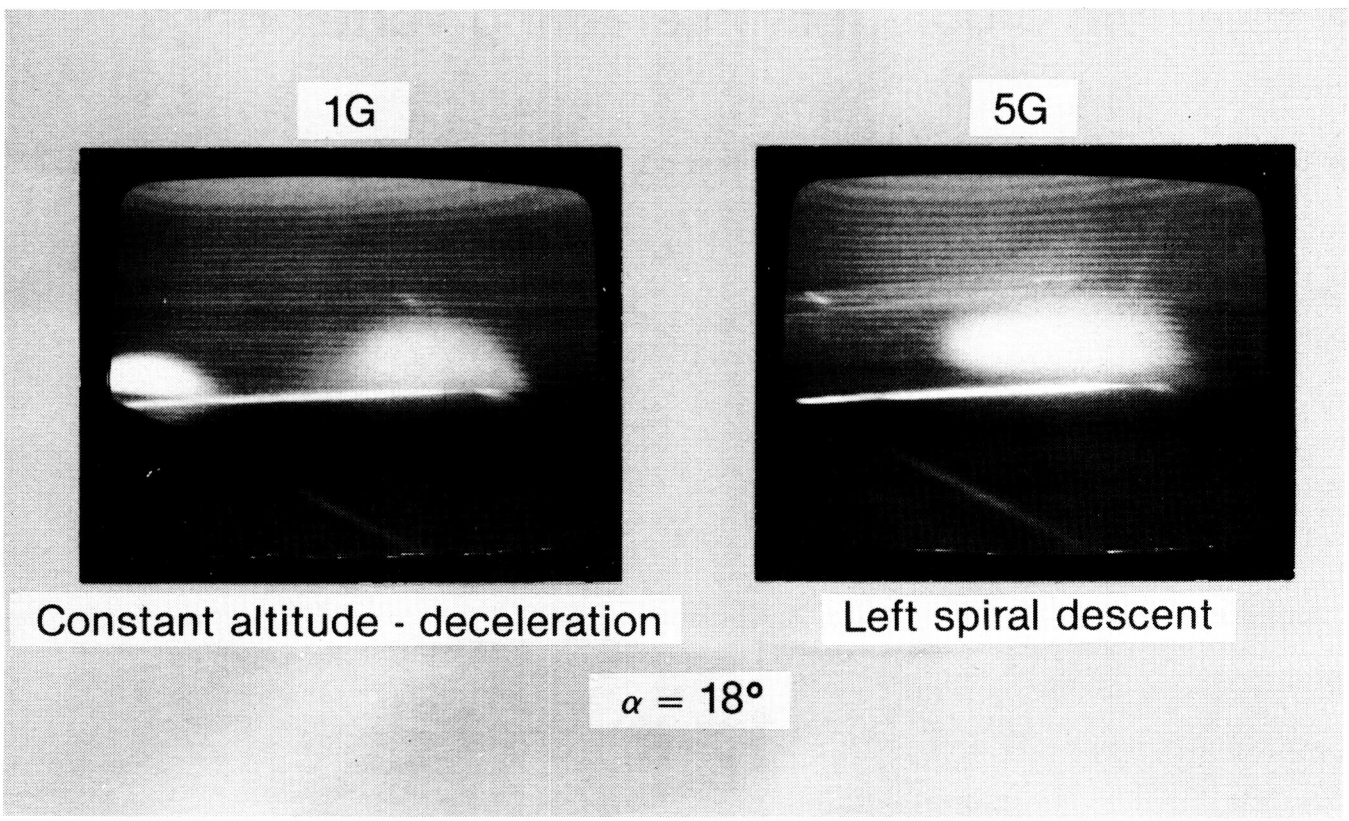
This photograph of the F-106B aircraft shows the location of the vapor screen light source on the side of the fuselage just forward of the vertical tail, the camera system on top of the fuselage just aft of the canopy, and the seeding probe just underneath the wing leading edge near the apex.

VISUALIZATION SCHEMATIC

This figure shows the relative locations of the seeding probe, vapor screen light sheet, and camera field of view on the F-106B aircraft. The field of view on the TV monitor screen illustrates the relative positons of the light sheet, fuselage, and wing leading and trailing edges.



The photographs of the TV monitor screen shown in this figure illustrate the observed variation of the leading-edge vortex system on the F-106B aircraft under two different flight conditions at an angle of attack of 18^{0}. The photograph on the left was taken during a constant altitude deceleration maneuver in which the angle of attack was slowly increased to maintain constant lift (1g flight). The photograph on the right was taken during a spiral descent (5g) maneuver during which the Mach number was held constant. Although the Mach and Reynolds numbers are different for these cases, they are representative of the wide variety of conditions which are routinely encountered in cruise and maneuver flight.



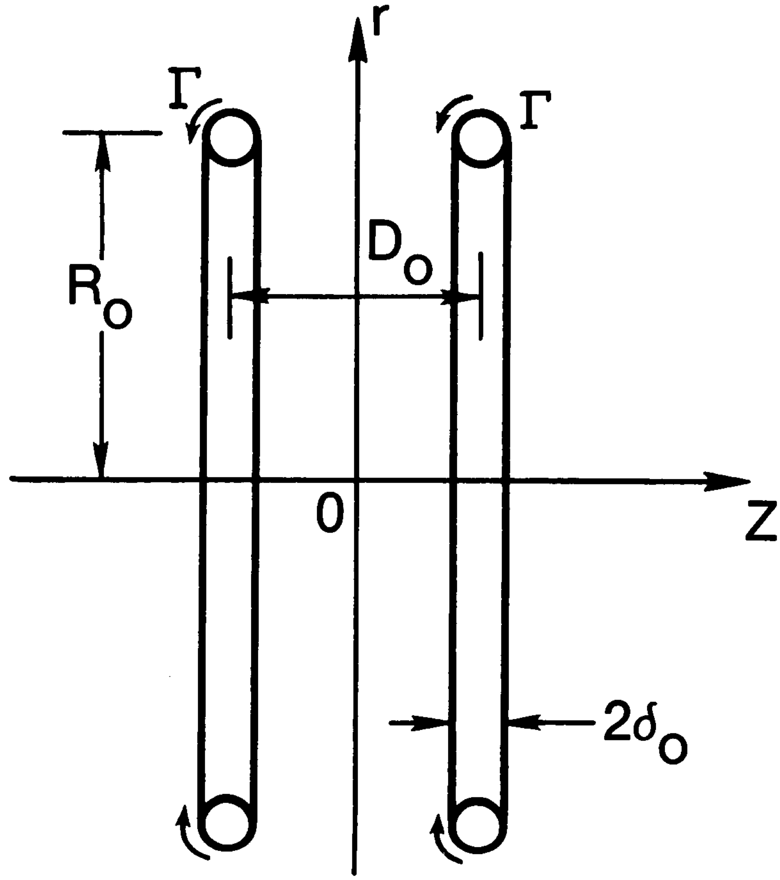
NUMERICAL STUDIES OF VORTEX FLOWS

Complex vortex flows occur frequently in many areas of fluid mechanics and are often poorly understood. Numerical techniques have been developed and applied to study three-dimensional flows. An example problem is the merging and decay of a pair of vortex rings.

- Physical intuition is lacking
- Example problem is interacting vortex rings
- Numerical results illustrate merging and decay

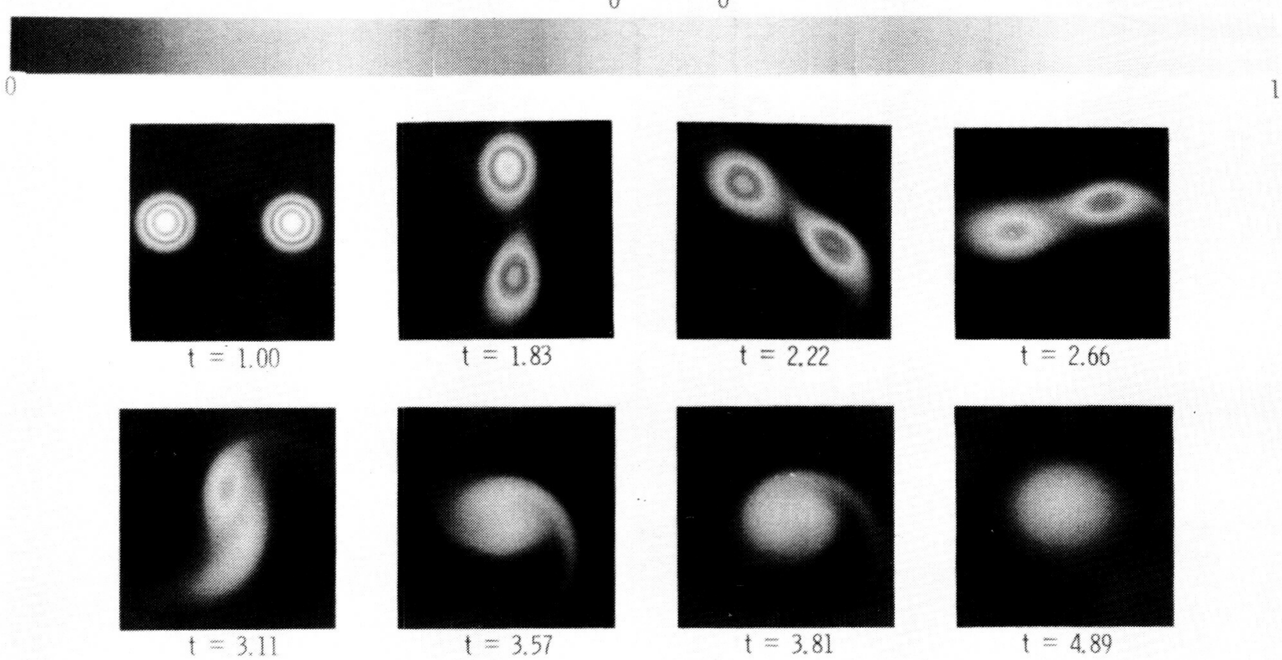
INITIAL GEOMETRY

This figure shows the initial geometry for the vortex ring calculations. Both rings have the same strength (Γ), radius (R_0), and core size (δ_0) and are separated by a distance D_0.



This figure illustrates a typical evolution of the vorticity for two right-moving interacting vortex rings with Reynolds number = 754 and D_o/δ_o = 6. Note that the displayed vorticity contours represent the vorticity distribution on a meridian plane cutting through the torus with only the contours centered at R_o being shown. The center of the torus is far below the contours and is not shown. The first ring, moving ahead initially, is stretching its radius and slowing down. In contrast, the second ring, moving behind initially, is contracting its radius and speeding up. The plane of the second ring passes over that of the first ring at t = 1.83. At this instant, the two rings switch the roles of leading and lagging. It is observed that the two points of local maximum vorticity cross over each other two more times at t = 3.11 and 3.81. Finally, the two points of local maximum vorticity merge into a single point for t = 3.81. A more detailed description of these calculations is presented in reference 2.

Two Vortex Rings, R_0 = 15, D_0 = 6, Re = 754



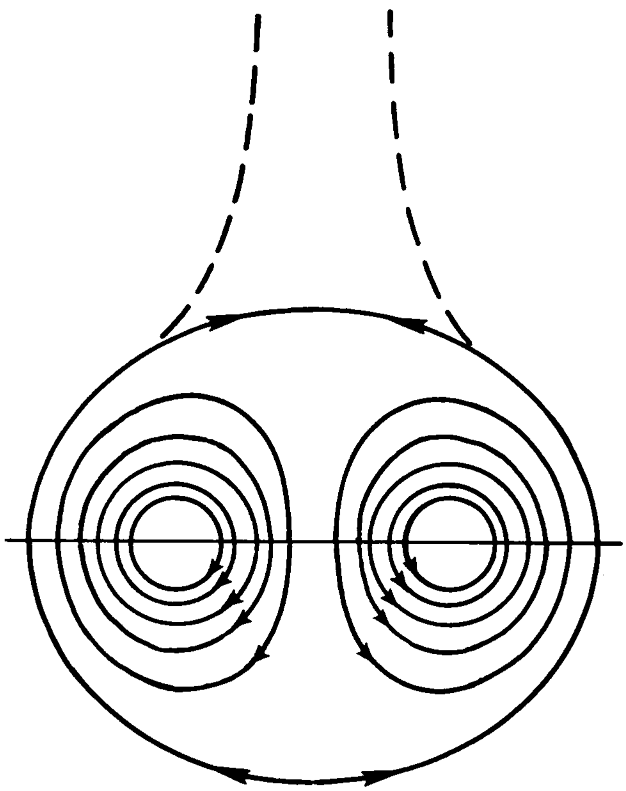
VORTEX DECAY IN THE ATMOSPHERE

Measurements of wake decay in ground facilities and in the atmosphere have shown considerable variation. Analytical predictions of atmospheric effects also vary greatly. An approximate analytical model has been developed to predict the effects of stratification, turbulence, and Reynolds number on wake lifetime.

- Understand effects of stratification, turbulence, and Reynolds number on wake persistence
- Historically difficult problem
- Approximate analytical model developed

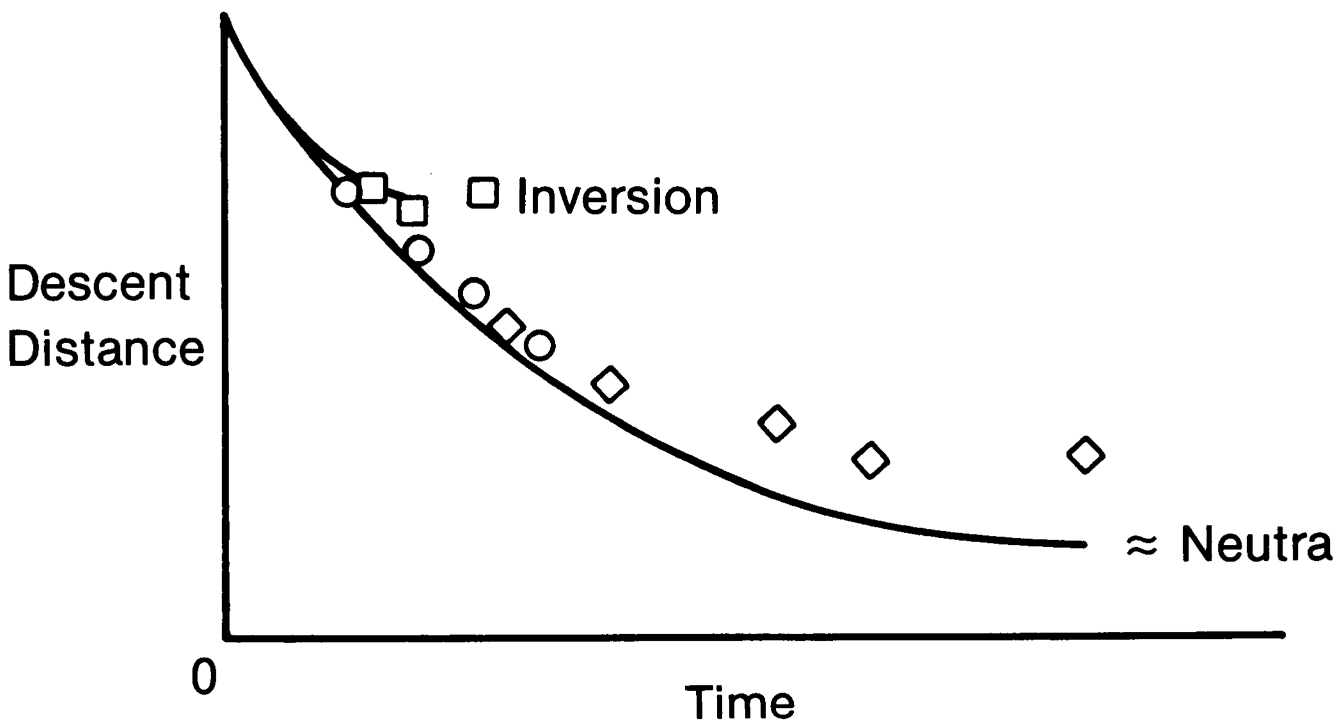
FLOWFIELD SCHEMATIC

This figure shows a schematic of the flowfield in the wake of a lifting wing, viewed in a coordinate system moving downward with the wake. As the roughly oval region of fluid descends, it is subject to several types of interaction with the surrounding atmosphere which promote decay. One interaction is proportional to the square of the wake descent velocity and is roughly analogous to the viscous forces which a solid body would experience. Wake decay is also enhanced by atmospheric turbulence which, in the absence of large scale instabilities, has an effect proportional to the vortex strength and turbulence level. In addition, if the atmosphere is stably stratified, the wake experiences a buoyancy force proportional to the density difference between the wake and surrounding atmosphere. These effects have been simulated in an approximate analysis to predict the motion and decay characteristics of wakes in the atmosphere.



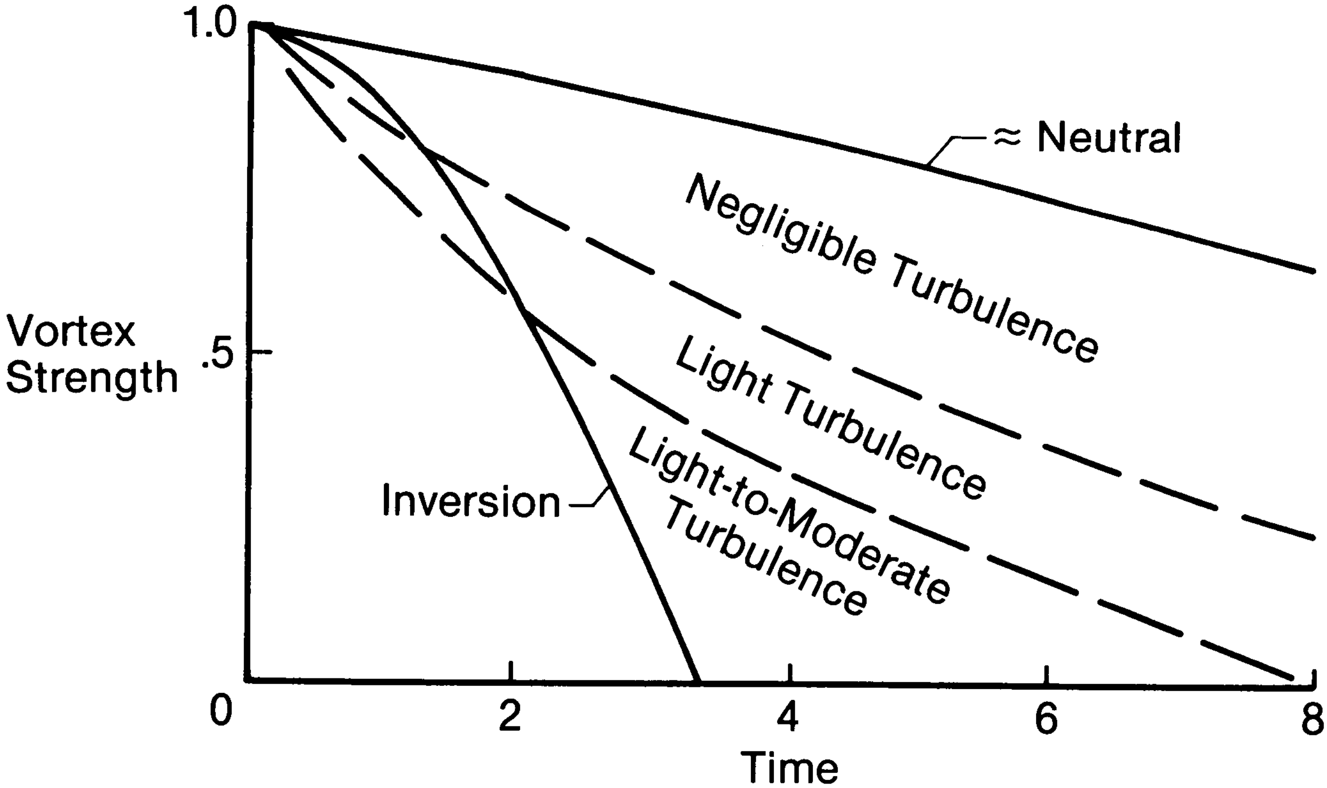
WAKE TRAJECTORIES

This figure shows a comparison of predicted wake trajectories and ground facility data from reference 3 for the range of density stratification commonly encountered in the atmosphere. The term "neutral" refers to an adiabatic decrease in density with altitude while the term "inversion" refers to a more rapid decrease which occurs when the temperature is increasing with altitude (ground colder than the atmosphere). As shown in the figure, this can have a large effect on wake lifetime.



PREDICTED WAKE DECAY

This figure shows predicted effects of stratification and turbulence on the decay of vortex strength. The curves labeled "neutral" and "inversion" correspond to the range of density stratification commonly encountered in the atmosphere with no turbulence effects included. The broken lines correspond to the "neutral" case with turbulence effects included and, for a large transport aircraft, represent approximate boundaries between negligible, light, and light-to-moderate turbulence. Typical aircraft separations in the terminal area correspond to normalized time values between about 4 and 8. Atmospheric conditions are therefore predicted to play a dominant role in determining wake lifetimes. Conditions of low turbulence and near neutral atmospheric stability are predicted to be especially conducive to long wake lifetimes.



SUMMARY

Due to the many applications in aerodynamics there is a broad spectrum of vortex-flow research. The level of physical understanding varies considerably; therefore the research technique is often tailored to the application.

- Experimental research underway to understand a wide variety of complex vortex flows

- Analytical techniques being applied to numerically simulate basic vortex physics and predict decay trends in the atmosphere

REFERENCES

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2. Liu, Grace C.; and Hsu, Chung-Hao: Numerical Studies of Interacting Vortices. NASA TM 86325, 1985.

3. Satran, Dale R.; Neuhart, Dan; Holbrook, G. Thomas; and Greene, George C.: Vortex Research Facility Improvements and Preliminary Density Stratification Effects on Vortex Wakes. AIAA Paper 85-0050, 1985.